BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 12055

SUBJECT: The Effects of Thermal Coatings and Insulation on the Thermal Behavior of the Skylab Orbital Workshop for the Solar Inertial Attitude - Case 620

DATE: December 22, 1970

FROM: D. P. Woodard
A. W. Zachar

ABSTRACT

The effects of internal insulation additions and external low absorptance coatings on the Skylab Orbital Workshop (OWS) are investigated parametrically using the Bellcomm Orbital Workshop (BOWS) thermal model. Results show that:

1. Low absorptance coating effectiveness increases non-linearly with increasing sun angle.
2. The individual effects of adding insulation and applying a low absorptance coating on OWS heat leak are opposed, independently additive, and create the possibility of biasing the OWS passive thermal characteristics relative to heater power and cooling requirements.

(NASA-CR-116356) THE EFFECTS OF THERMAL COATINGS AND INSULATION ON THE THERMAL BEHAVIOR OF THE SKYLAB ORBITAL WORKSHOP FOR THE SOLAR INERTIAL ATTITUDE (Bellcomm, Inc.) 26 p

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MEMORANDUM FOR FILE

Two previous memoranda[(1), (2)] have described the Skylab Orbital Workshop thermal model as received from MSFC/S&E-ASTN (MOWS) and documented its generalization to accept time-varying external absorbed heat input data. The generalized thermal model, termed BOWS in Reference 2, has been used to investigate the effects of external thermal coatings, internal insulation changes, and sun angle (Beta) variations on the thermal behavior of the OWS when in a 235 NM circular, solar oriented orbit. The solar orientation and sun angle definition are shown in Figure 1.

The internal insulation changes considered in this report are summarized in Table 1, which compares the original (uninsulated) and new (insulated) foam insulation schemes. As shown in Table 1, the forward joint has an added inch of foam insulation. The aft joint, aft LH_2 tank fuel dome, and the common bulkhead which was uninsulated in the MOWS model, are now covered with 3.5 inches of foam. New thermal model nodes have been added in the common bulkhead region and thermal conductor modifications have been made in the other regions to accommodate these insulation changes. The insulation characteristics described in Reference 1 have been retained.

The original (unstriped) developed OWS exterior surface is shown in Figure 2. The two low absorptance striping patterns, T225 and WT225, are shown similarly in Figures 3 and 4. In both patterns, the 22.5 degree axial stripes overlay the interior OWS regions referred to in Reference 1 as the upper and lower above crew quarters regions. The narrow (T225) circumferential stripe covers a 180 degree circumferential portion of the meteoroid shield bottom which is external to the interior crew quarters region. The wide (WT225) circumferential stripe extends axially over the complete meteoroid shield bottom and thus affects both the crew quarters and below crew quarters regions. Both patterns are symmetrical with respect to the subsolar line.

The additions of insulation to the interior of the OWS and low solar absorptance striping to the exterior produce conflicting effects on the OWS thermal behavior. Insulation provides

increased isolation of the two joint regions, the aft LH_2 tank dome, and the common bulkhead from the external environment. Heat leaks* through these regions are thus decreased. The low absorptance striping patterns result in a decrease in external meteoroid shield temperatures with a corresponding increase in the heat leak through the crew quarters and below crew quarters regions.

The results presented in this memorandum are based upon an internal OWS atmospheric temperature of 70°F in the below crew quarters region immediately forward of the common bulkhead. This was done in a manner which simulates, computationally, the action of the Airlock Module active thermal control system. For clarity in our analysis and to isolate the effects of insulation and striping changes, no other internal heat sources were used.

Effect of Insulation Additions

The BOWS thermal model divides the OWS interior sidewall surface into 80 nodes, i.e., 8 circumferential by 10 axial divisions. Using the previous definition of heat leak, the total OWS heat leak, Q_{TOTAL}, therefore, is the sum of 80 time-varying heat leak components. The average of Q_{TOTAL} over an orbital period, $\overline{Q_{TOTAL}}$, together with the orbital averages for the 10 OWS axial components, are given in Table 2. The Uninsulated-Unstriped and Insulated-Unstriped OWS configurations are compared for Beta angles of 0, 30, 60.5, and 73.5 degrees.

As shown in Table 2, $\overline{Q_{TOTAL}}$ is decreased significantly by the addition of insulation. For all Beta angles and for both insulated and uninsulated cases, heat leak through the common bulkhead (CB) is the largest single component of $\overline{Q_{TOTAL}}$. This heat leak component, as well as the leak components through the forward and aft joints and aft fuel dome, is lowered when insulation is added. The remaining regions, for which the insulation is unchanged (the UFD, LFD, UACQSW, CQSW, and BCQSW), show heat leak increases due indirectly to the decrease in thermal conductance of the neighboring insulated regions. We would expect, therefore, to see a general increase in the interior sidewall and atmospheric temperatures for the insulated case. This is indeed verified by the data given in Table 3 which compares these temperatures at a Beta angle of Zero degrees.

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* Heat leak is taken to be the net heat rate, positive from inside to outside, passing through a given inside OWS node.

Table 2 shows that the total OWS heat leak is not greatly affected by variations in Beta from 0 to 30 degrees. However, above 30 degrees, $\overline{Q_{TOTAL}}$ decreases significantly. At 73.5 degrees, $\overline{Q_{TOTAL}}$ is negative, representing a net heat gain to the OWS from the external environment. The only net positive heat leak components for β=73.5° occur through the UFD, AJ, AFD, and CB regions. The decrease in the CB heat leak component due to insulation is the principal cause of the net heat gain to the OWS at 73.5 degrees.

Figure 5 summarizes the effect of insulation additions by showing the decrease of $\overline{Q_{TOTAL}}$ as a function of Beta. We will show later that this decrease in $\overline{Q_{TOTAL}}$ is additive to the effect of meteoroid shield striping.

Effect of Striping

The use of a lower solar absorptance (α) coating on the sun side portions of the OWS exterior results in a net increase in total orbit average heat leak, $\overline{Q_{TOTAL}}$, as well as localized changes in the exterior and interior temperatures and heat leak components. Figures 6 through 9 show the local effects of both striping patterns (T225 and WT225, Figures 3 and 4, respectively) on the external meteoroid shield top and bottom temperatures and heat leak flux (BTU/hr ft^2) distributions. Note, in particular, the shield temperature decrease and negative heat leak flux decrease in the striped regions. The small differences in the values of temperature and heat leak for nodes symmetrical with respect to the subsolar line are due to the asymmetrical Earth albedo and I.R. heat loads.

Figures 10 and 11 show the interior circumferential temperature distributions for sidewall nodes located radially inward from the striped meteoroid shield for β=73.5°. As shown in Figure 10, the above crew quarters internal sidewall nodes directly behind the striped meteoroid shield (i.e., the internal nodes behind external nodes 512 and 513) show a drop in temperature of about 10°F between the unstriped and WT225 striped cases. Figure 11 shows a temperature drop of approximately 20°F for the crew quarters and below crew quarters interior sidewall nodes (those behind exterior nodes 520 to 524) between the unstriped and WT225 cases. This greater interior sidewall temperature decrease is due to the wider stripe in this region, see Figure 4.

In a manner similar to that used in Table 2, $\overline{Q_{TOTAL}}$ and its constituent heat leak components (averaged over an orbit) are tabulated in Table 4. Here we have a comparison between the basic insulated-unstriped configuration and the two insulated-striped configurations. The heat leak components affected by striping are marked by the shaded region across the tabulation. In all cases, except for the upper above crew quarters region which is least affected by striping, the leak components increase with increased striping. The heat leak components not axially adjacent to the exterior striped regions show a decrease with an increase in striping.* Though not specifically investigated, this appears to be due to the lower internal surface and gas temperatures associated with and resulting from the striping patterns. $\overline{Q_{TOTAL}}$ differences, as obtained from Table 4, for the two striping patterns are shown in Figure 12 as a function of Beta.

Combined Effects of Insulation and Striping

The effects of insulation and striping on $\overline{Q_{TOTAL}}$ may be added independently, i.e., superposition is valid. This is shown in Figure 13. The solid curve shows $\overline{Q_{TOTAL}}$ for the uninsulated T225 striping configuration as computed. The dashed curve shows $\overline{Q_{TOTAL}}$ for the same configuration but obtained by adding the effects of insulation and striping as given in Figures 5 and 12, respectively, to the insulated WT225 configuration. From this comparison, we conclude the effects are additive.

Figure 14 summarizes the dependence of $\overline{Q_{TOTAL}}$ for all configurations as a function of Beta. The uninsulated WT225 striped configuration, shown dashed, is estimated in the manner of the previous paragraph. The 73.5 degree Beta point as computed is 1301 BTU/hr; as estimated, 1370 BTU/hr.

*With the exception of the insulated aft joint component, which is small.

Conclusions

Figure 14 shows the effect of adding insulation and striping to the OWS from an overall thermal energy balance viewpoint. The insulation and striping cases shown result in a total average heat leak variation of about 2000 BTU/hr (1800 at β=0 and 2200 at β=73.5). The choice of a particular combination of insulation and striping depends on the anticipated average internal heat load and its range. This choice should be made considering the available heater power at low sun angles and active cooling capacity at high sun angles. Local effects must also be considered, as for example, locating the striping exterior to the crew quarters region of the OWS where it is most effective in eliminating the environmental heat gain at β=73.5° and where the higher internal OWS heat loads are likely to occur.

D. P. Woodard

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A. W. Zachar

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1022-$\frac{\text{DPW}}{\text{AWZ}}$-tla

Attachments
Tables 1-4
Figures 1-14

REFERENCES

1. Woodard, D. P. and Zachar, A. W., "Skylab Orbital Workshop Thermal Model," Bellcomm Memorandum for File, June 30, 1970.

2. Woodard, D. P. and Zachar, A. W., "Generalization of the Skylab Orbital Workshop Thermal Model to Accept Transient External Absorbed Heat Input Data," Bellcomm Memorandum for File, September 28, 1970.

TABLE 1
COMPARISON OF ORIGINAL (UNINSULATED) AND NEW (INSULATED)
OWS INTERNAL FOAM INSULATION SCHEMES

OWS INTERIOR AXIAL DIVISION	ORIGINAL THICKNESS* INCHES	NEW THICKNESS INCHES
UPPER LH_2 TANK FORWARD DOME (UFD)	0.5	0.5
LOWER LH_2 TANK FORWARD DOME (LFD)	0.5	0.5
FORWARD JOINT (FJ)	0.5	1.5
UPPER ABOVE CREW QUARTERS SIDEWALL (UACQSW)	1.0	1.0
LOWER ABOVE CREW QUARTERS SIDEWALL (LACQSW)	1.0	1.0
CREW QUARTERS SIDEWALL (CQSW)	1.0	1.0
BELOW CREW QUARTERS SIDEWALL (BCQSW)	1.0	1.0
AFT JOINT (AJ)	0.5	3.5
AFT LH_2 TANK FUEL DOME (AFD)	0.5	3.5
COMMON BULKHEAD (CB)	0.0	3.5

*DESCRIBED IN REFERENCE 1.

TABLE 2
EFFECT OF INSULATION ADDITIONS ON OWS HEAT LEAK (BTU/HR)
AS A FUNCTION OF BETA ANGLE

	$\beta = 0°$		$\beta = 30°$		$\beta = 60.5°$		$\beta = 73\ 5°$	
	UI–US	I–US	UI–US	I–US	UI–US	I–US	UI–US	I–US
$\overline{Q_{TOTAL}}$	2140.6	1634.8	2092.7	1580.2	1414.0	948.5	–616.1	–896.6
UFD	195.3	206.4	192.5	204.7	163.7	172 8	66 2	69.7
LFD	92.5	115.5	90.6	113.4	52.5	67.1	–64.6	–73.1
FJ*	70.4	26.3	68.6	25.8	31.7	13.6	–84.0	–24.0
UACQSW	21.7	53.2	11.1	42.9	–84.9	–62.6	–356.0	–358.3
LACQSW	–25.4	–8.6	–37.5	–20.4	140.1	–127.1	–417.4	–410.5
CQSW	17.3	50.3	–.9	33.3	–137.9	–109.7	–507.6	–489.3
BCQSW	36.9	189.0	28.3	181.1	–67.1	68.7	–330.6	–248.8
AJ*	109.4	30.4	109.8	30.4	78.8	24.8	–11.2	7.3
AFD*	321.0	211.8	320.3	211.7	277.4	186.4	134.6	101.7
CB*	1301.6	760.6	1309.0	757.3	1239 9	714 5	954.5	529.6
RUN	052170	061770	062270	061670	061970	061270	062470	061570

*INDICATES INSULATION ADDITIONS AS SHOWN IN TABLE 1

CODE: UI–US - UNINSULATED, UNSTRIPED.
I–US - INSULATED, UNSTRIPED.

TABLE 3

ORBIT-AVERAGE OWS INTERIOR WALL AND ATMOSPHERE TEMPERATURES, $\beta = 0^\circ$

INTERIOR WALL TEMPERATURES (°F)		
OWS LOCATION	UI-US	I-US
UFD	62.0	63.2
LFD	61.4	62.3
FJ	59.3	62.7
UACQSW	62.3	63.4
LACQSW	62.6	63.8
CQSW	61.7	63.4
BCQSW	56.8	59.9
AJ	50.0	58 8
AFD	50.8	57.0
CB	51.8	57.8

ATMOSPHERE TEMPERATURES (°F)		
OWS LOCATION, NODE	UI-US	I-US
BELOW CREW QUARTERS, 600	71.4	71.1
CQ WORK COMPARTMENT, 601	70.0	70.0
CQ SLEEP COMPARTMENT, 602	69.7	69.9
CQ WASTE COMPARTMENT, 603	69.2	69.4
CQ FOOD COMPARTMENT, 604	69.1	69.3
CQ SLEEP COMPARTMENT, 605	69.0	69.1
ABOVE CREW QUARTERS, 606	69.0	69.2
UPPER FORWARD DOME, 607	68.6	69.9

CODE: UI-US UNINSULATED, UNSTRIPED
I-US INSULATED, UNSTRIPED

TABLE 4
EFFECT OF EXTERNAL STRIPING PATTERNS ON OWS HEAT LEAK (BTU/HR)
AS A FUNCTION OF BETA ANGLE

	$\beta = 0^\circ$			$\beta = 30^\circ$			$\beta = 60.5^\circ$			$\beta = 73.5^\circ$		
	I-US	I-T22 5	I-WT22.5	I-US	I-T22 5	I-WT22.5	I-US	I-T22.5	I-WT22.5	I-US	I-T22.5	I-WT22.5
$\overline{Q}_{TOTAL}$	1634.8	2357.9	2909.3	1580 2	2303 0	2868 5	948 5	1821.9	2510.6	−896.6	221.3	1090 4
UFD	206.4	187.7	174.8	204.7	183.7	170 1	172.8	149 5	138.4	69.7	39.0	18 6
LFD	115.5	104.2	91.6	113.4	98.9	84.8	67.1	52.1	45 8	− 73.1	− 94.8	−115 6
FJ	26 3	24.7	21.0	25.8	23.4	19.2	13.6	11 4	8.6	− 24.0	− 27.4	− 33.6
UACQSW	53.2	120.8	103.2	42.9	108.3	88.5	− 62.6	18.9	.3	−358.0	−254.4	−285.0
LACQSW	−8.6	106.7	127.7	−20.4	95.8	116.9	−127.1	12.4	36.4	−410.5	−233.5	−204.1
CQSW	50.3	419.0	782.3	33.3	411.8	789.1	−109.7	339.4	783.6	−489.3	92.5	673.4
BCQSW	189.0	434.7	687.1	181.1	433.7	692.9	68.7	370.0	676.1	−248.8	141.9	542.8
AJ	30.4	32 3	34 5	30 4	32.0	34.3	24.8	26.8	29.5	7.3	9.7	13 1
AFD	211.8	208.5	206.7	211.7	206.4	203.8	186.4	181 3	178.5	101.7	93.0	88.5
CB	760.6	717.6	680 4	757.3	708.9	669.0	714.5	660.2	613.3	529.6	455 2	392 4

CODE: I-US INSULATED, UNSTRIPED
I-T22.5 INSULATED, T22.5 STRIPING
I-WT22.5 INSULATED, WT22.5 STRIPING

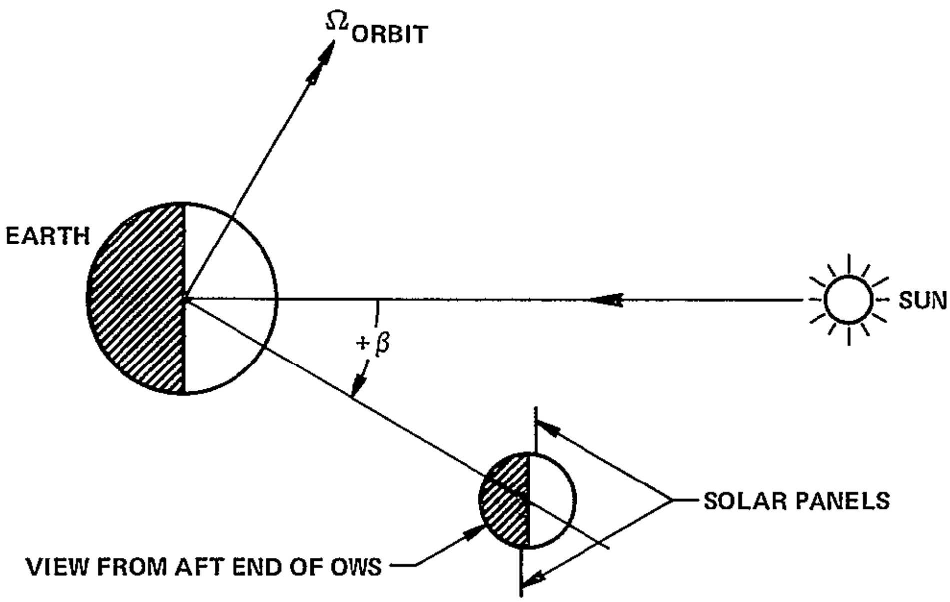

FIGURE 1 - SOLAR INERTIAL ATTITUDE

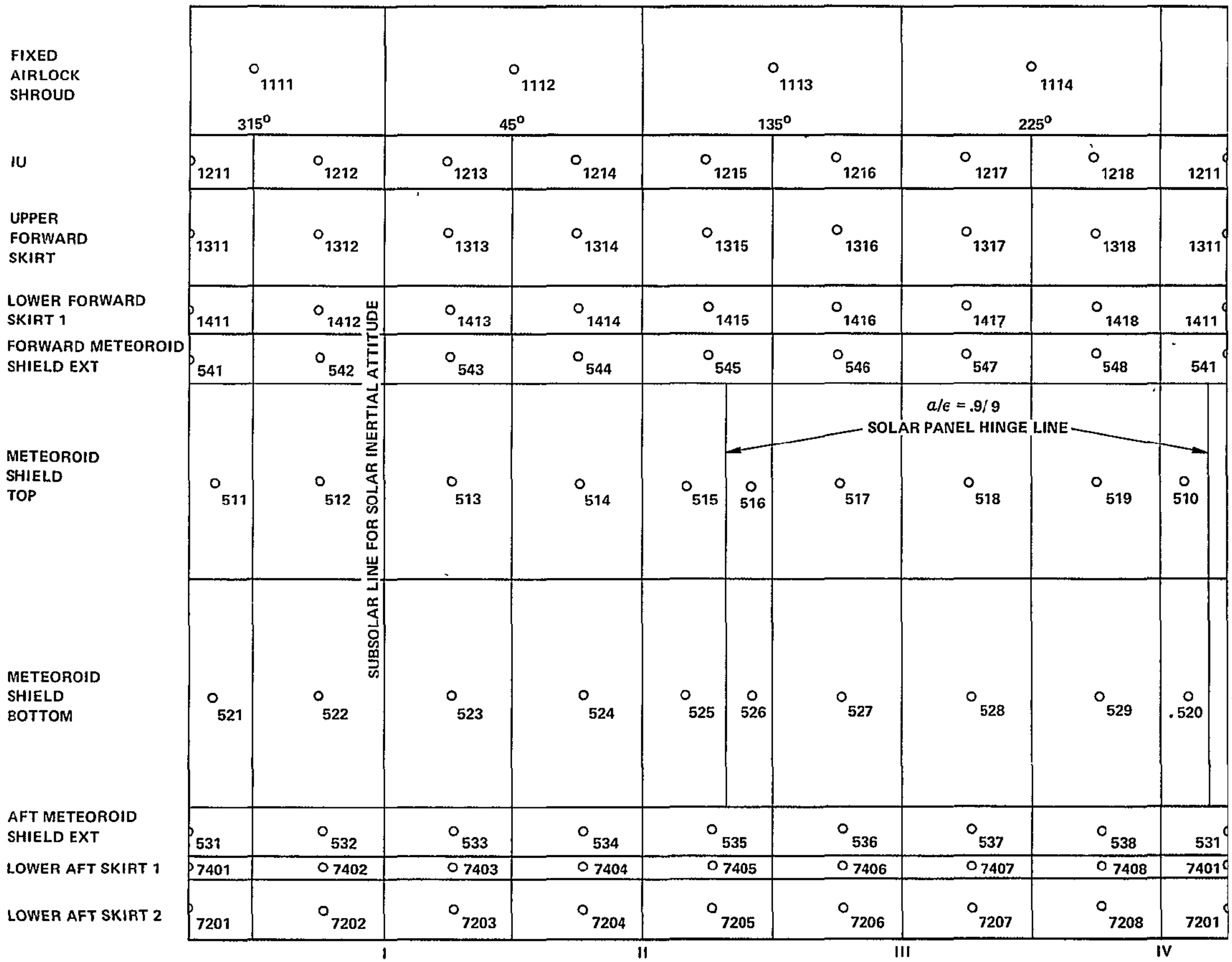

FIGURE 2 - CIRCUMFERENTIAL LOCATION OF EXTERIOR THERMAL NODES — UNSTRIPED

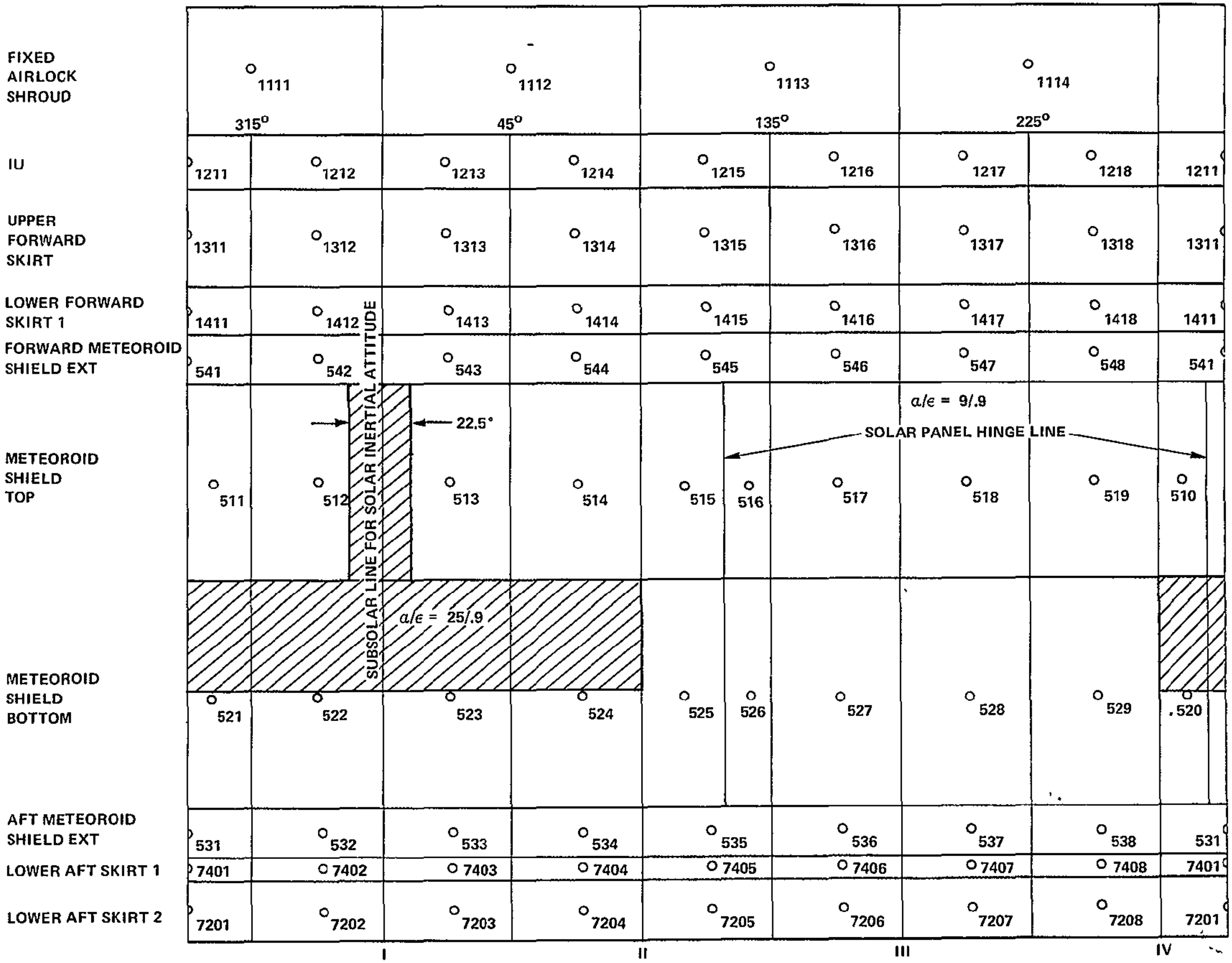

FIGURE 3 - CIRCUMFERENTIAL LOCATION OF EXTERIOR THERMAL NODES — T225 STRIPING

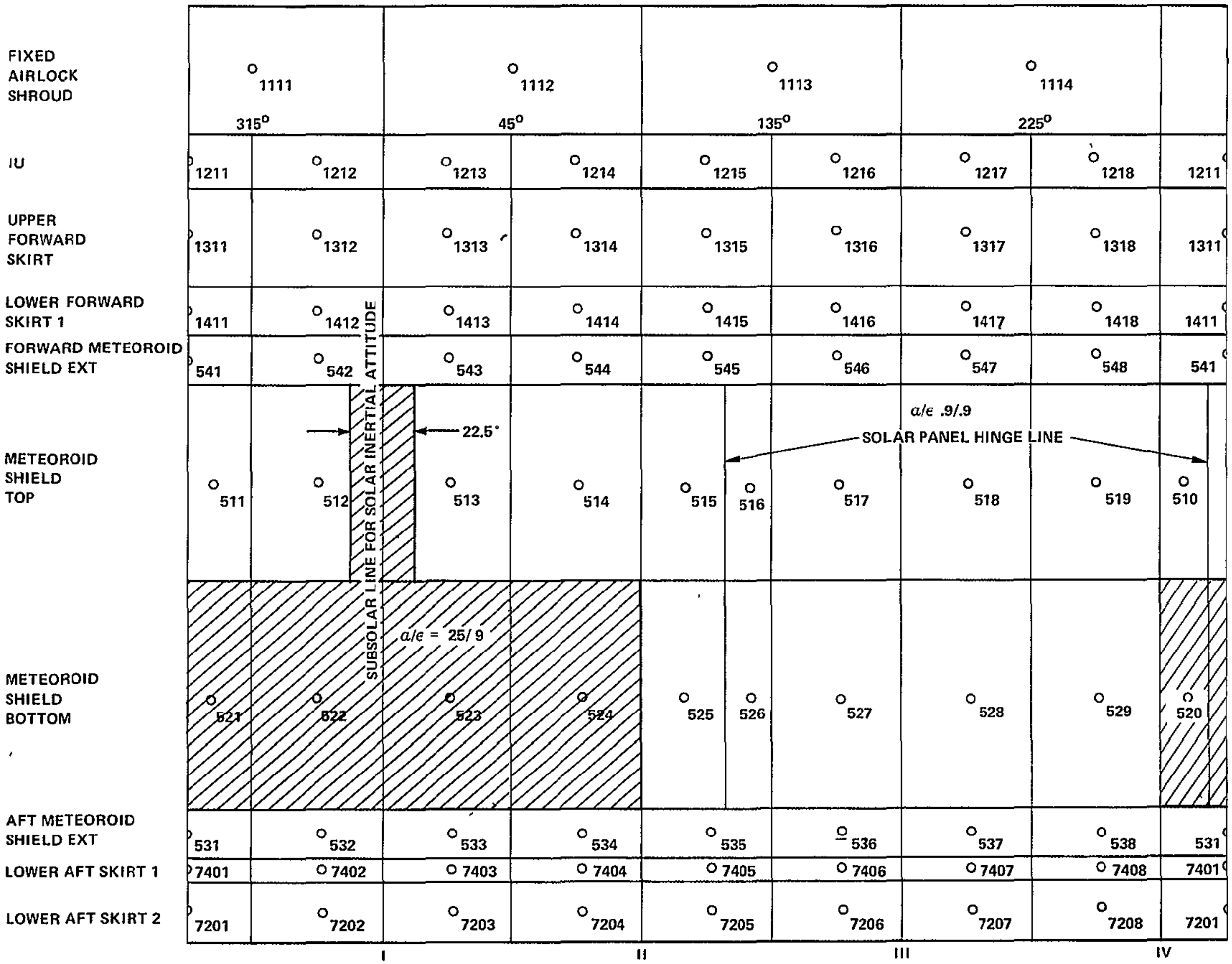

FIGURE 4 - CIRCUMFERENTIAL LOCATION OF EXTERIOR THERMAL NODES — WT225 STRIPING

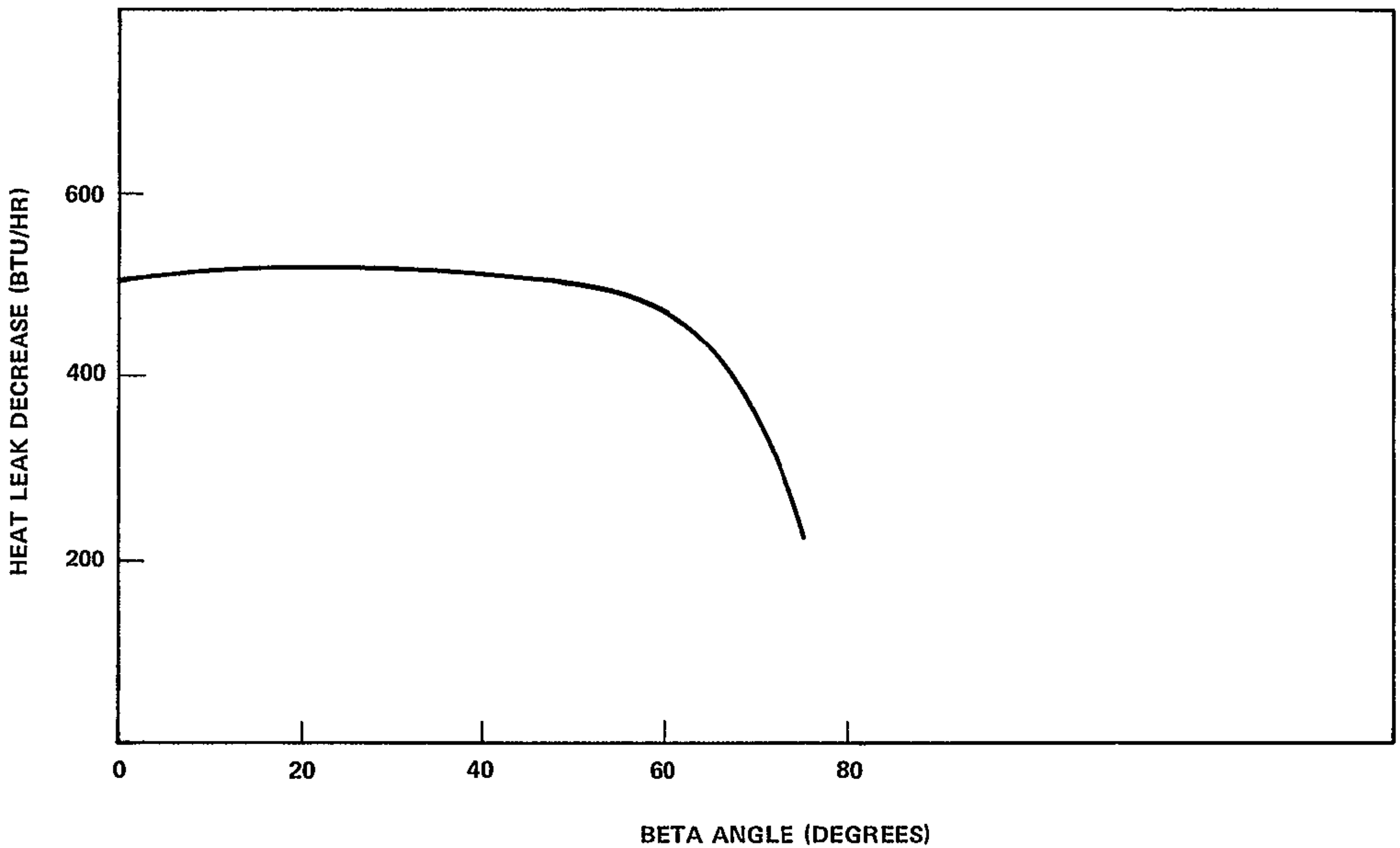

FIGURE 5 - OWS HEAT LEAK DECREASE RESULTING FROM INSULATION ADDITIONS AS A FUNCTION OF BETA ANGLE

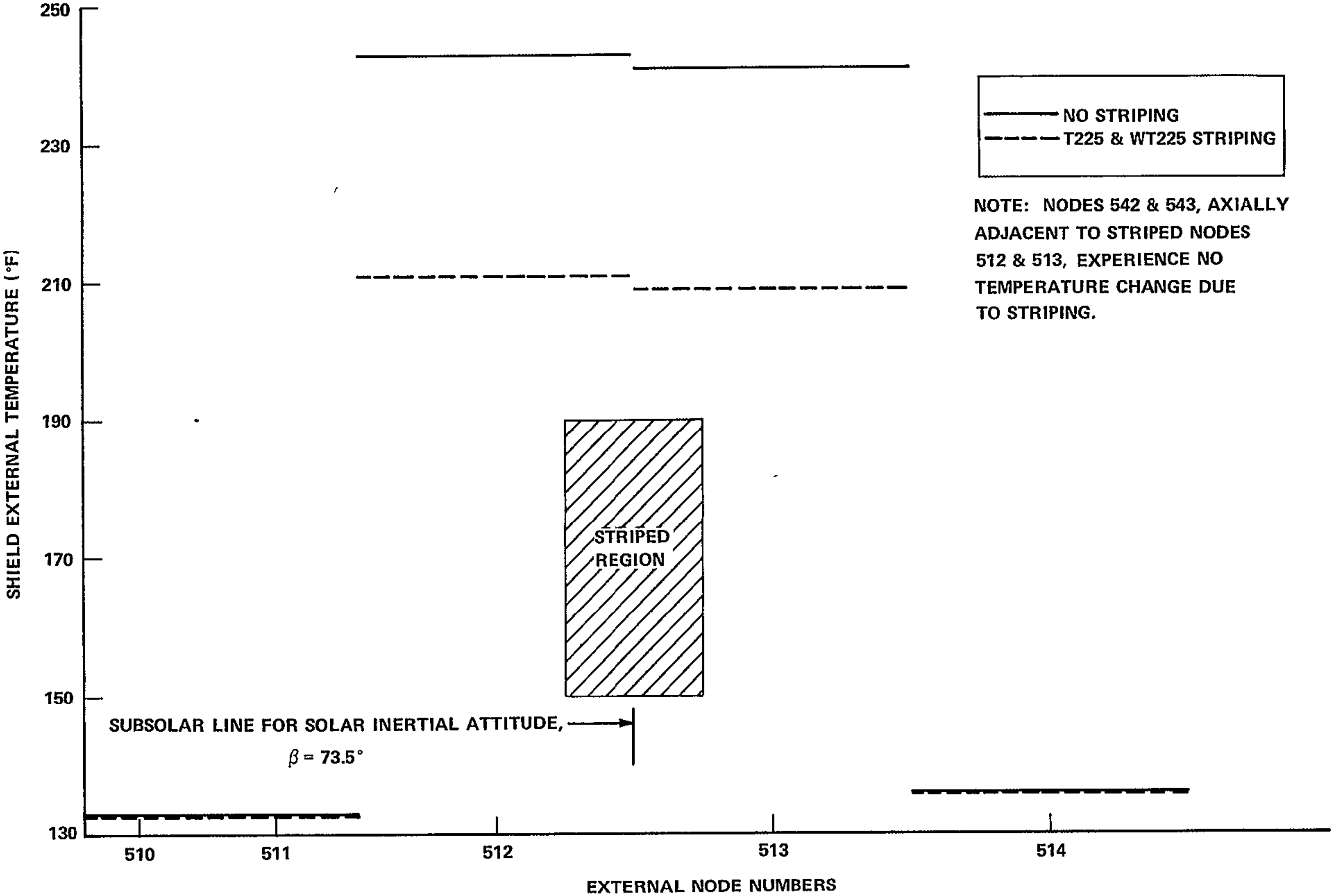

FIGURE 6 - METEOROID SHIELD TOP-PARTIAL CIRCUMFERENTIAL EXTERNAL ORBIT AVERAGE TEMPERATURE DISTRIBUTION

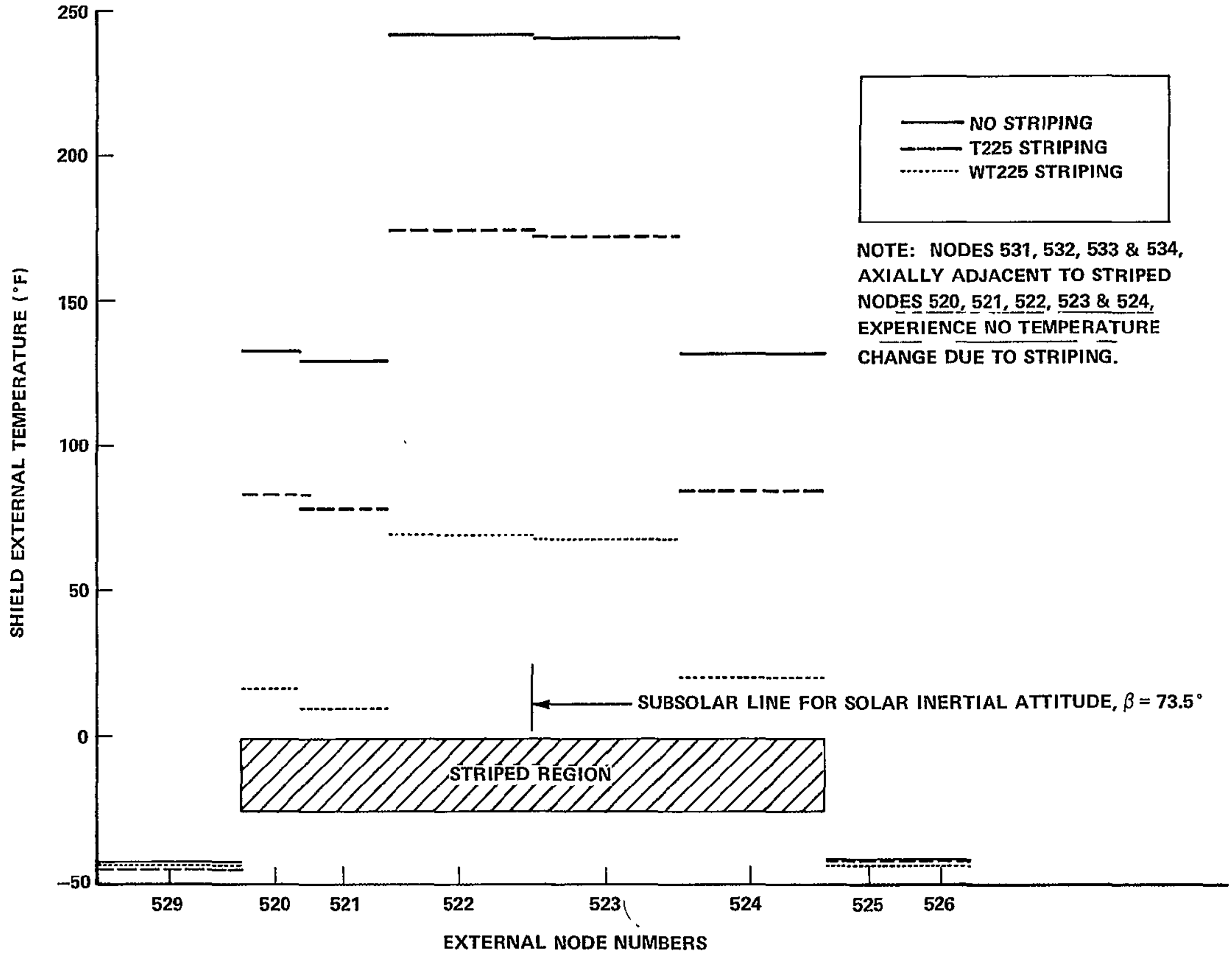

FIGURE 7 - METEOROID SHIELD BOTTOM — PARTIAL CIRCUMFERENTIAL EXTERNAL ORBIT AVERAGE TEMPERATURE DISTRIBUTION

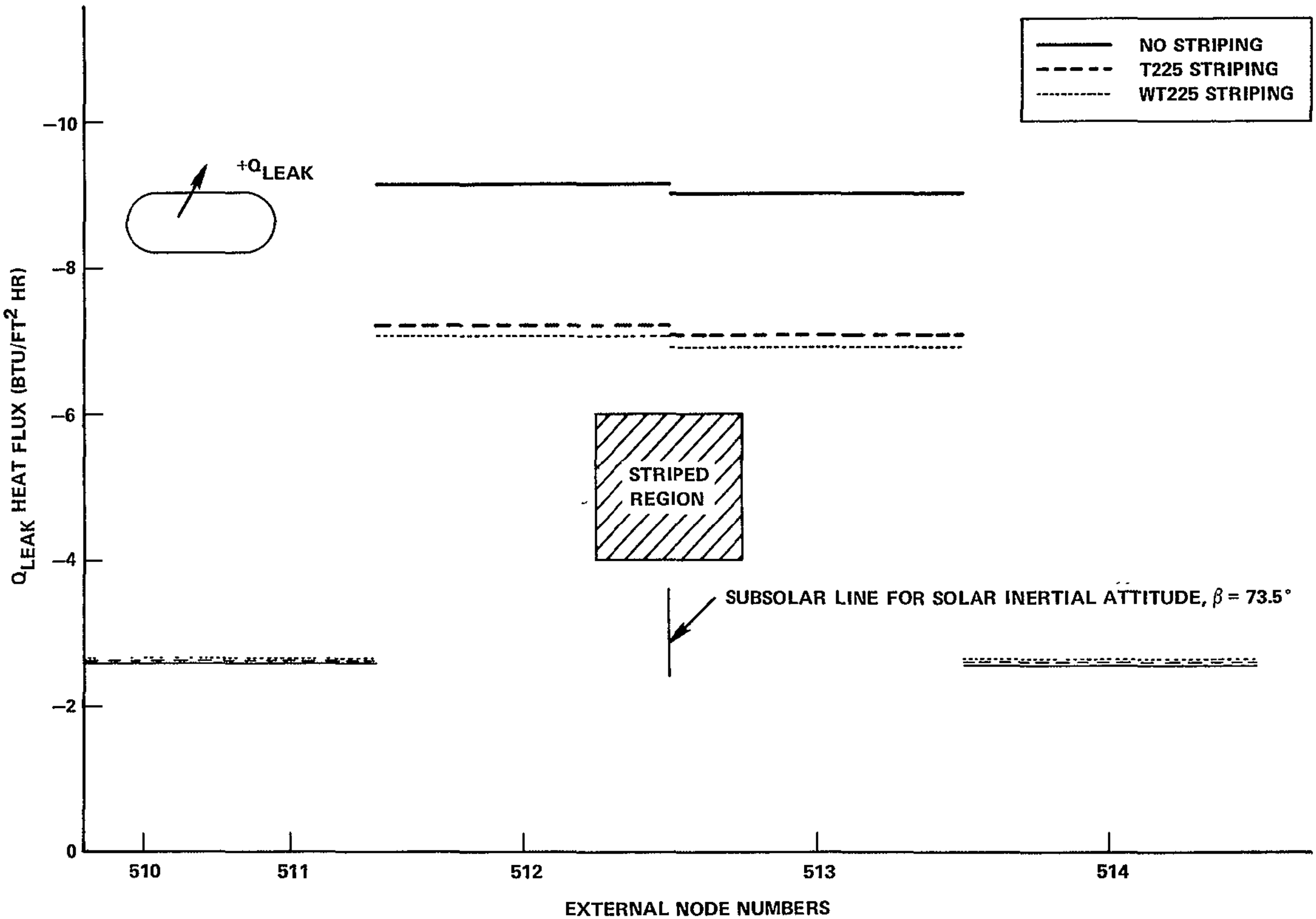

FIGURE 8 - METEOROID SHIELD TOP — PARTIAL CIRCUMFERENTIAL ORBIT AVERAGE HEAT FLUX DISTRIBUTION

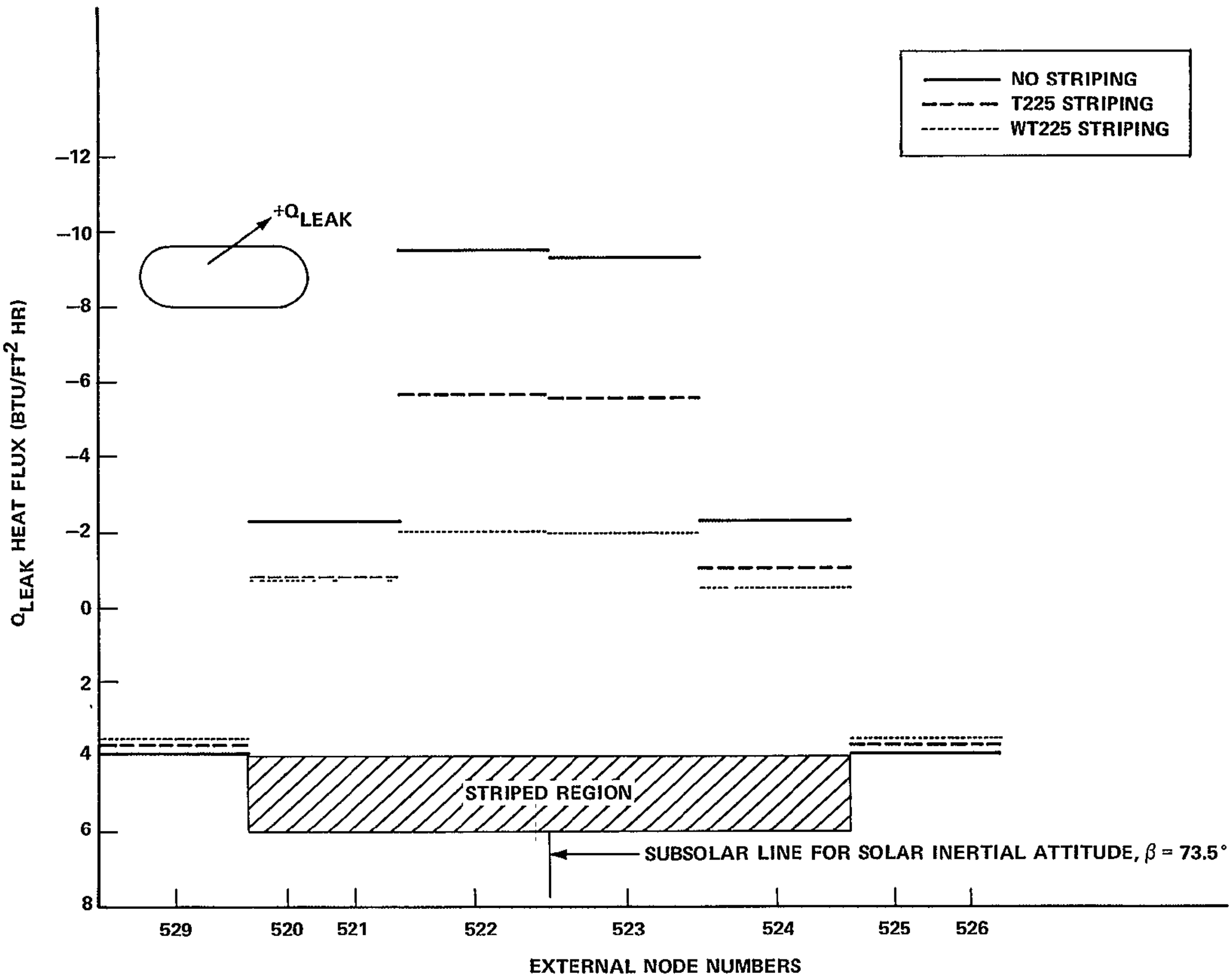

FIGURE 9 - METEOROID SHIELD BOTTOM — PARTIAL CIRCUMFERENTIAL ORBIT AVERAGE HEAT FLUX DISTRIBUTION

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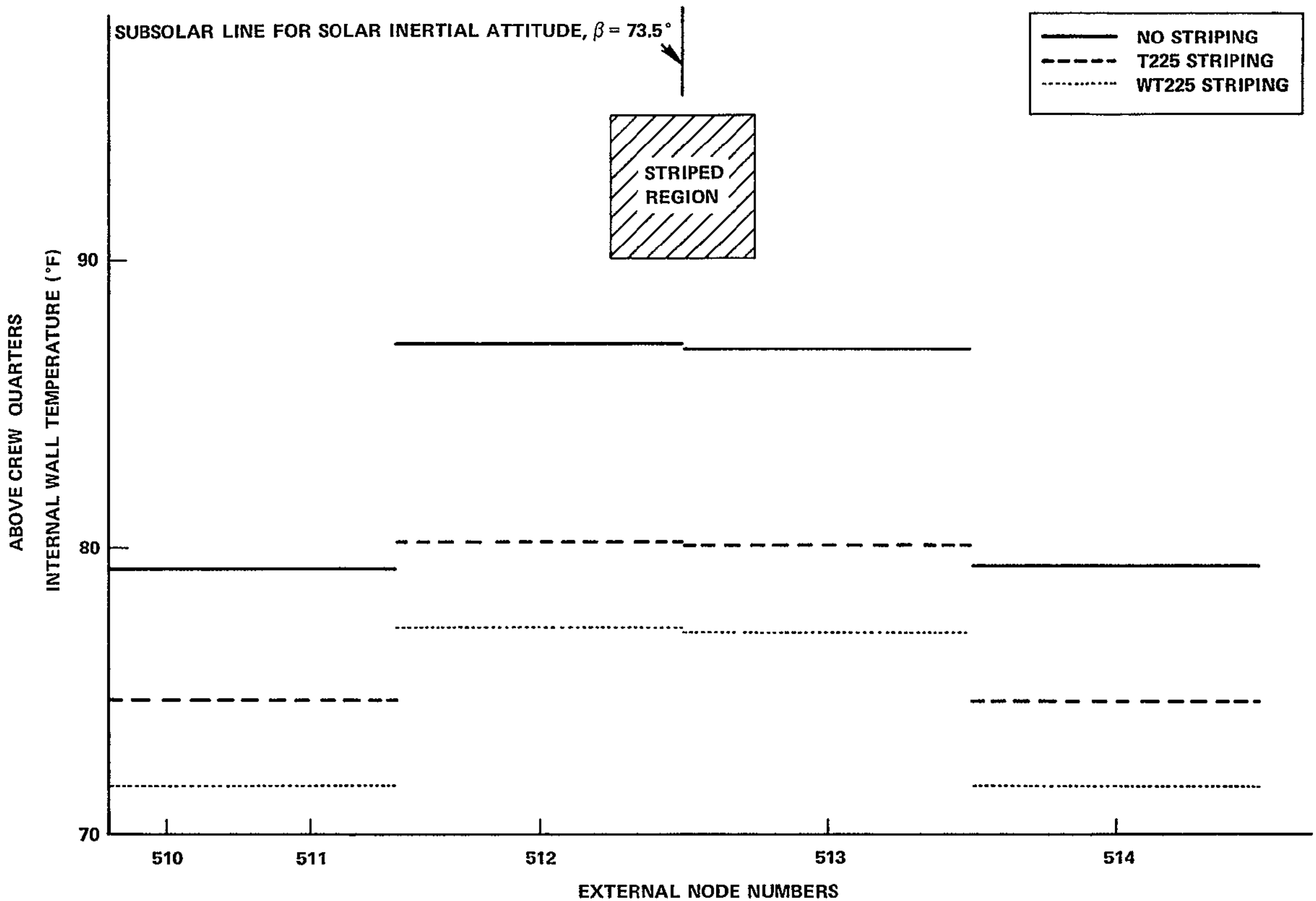

FIGURE 10 - METEOROID SHIELD TOP — PARTIAL CIRCUMFERENTIAL ORBIT AVERAGE ABOVE CREW QUARTERS INTERNAL TEMPERATURE DISTRIBUTION

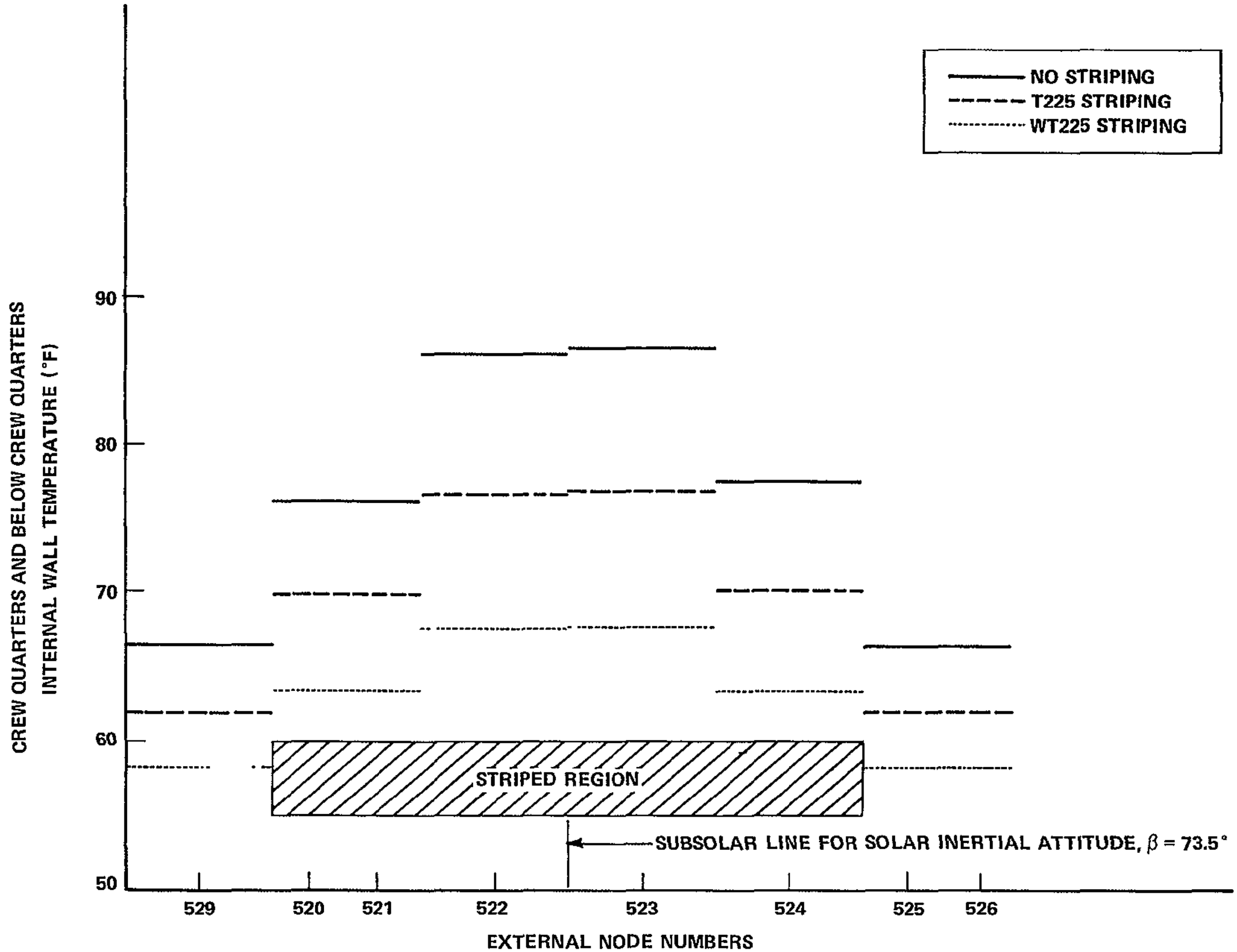

FIGURE 11 - METEOROID SHIELD BOTTOM — PARTIAL CIRCUMFERENTIAL ORBIT AVERAGE CREW QUARTERS AND BELOW CREW QUARTERS INTERNAL TEMPERATURE DISTRIBUTION

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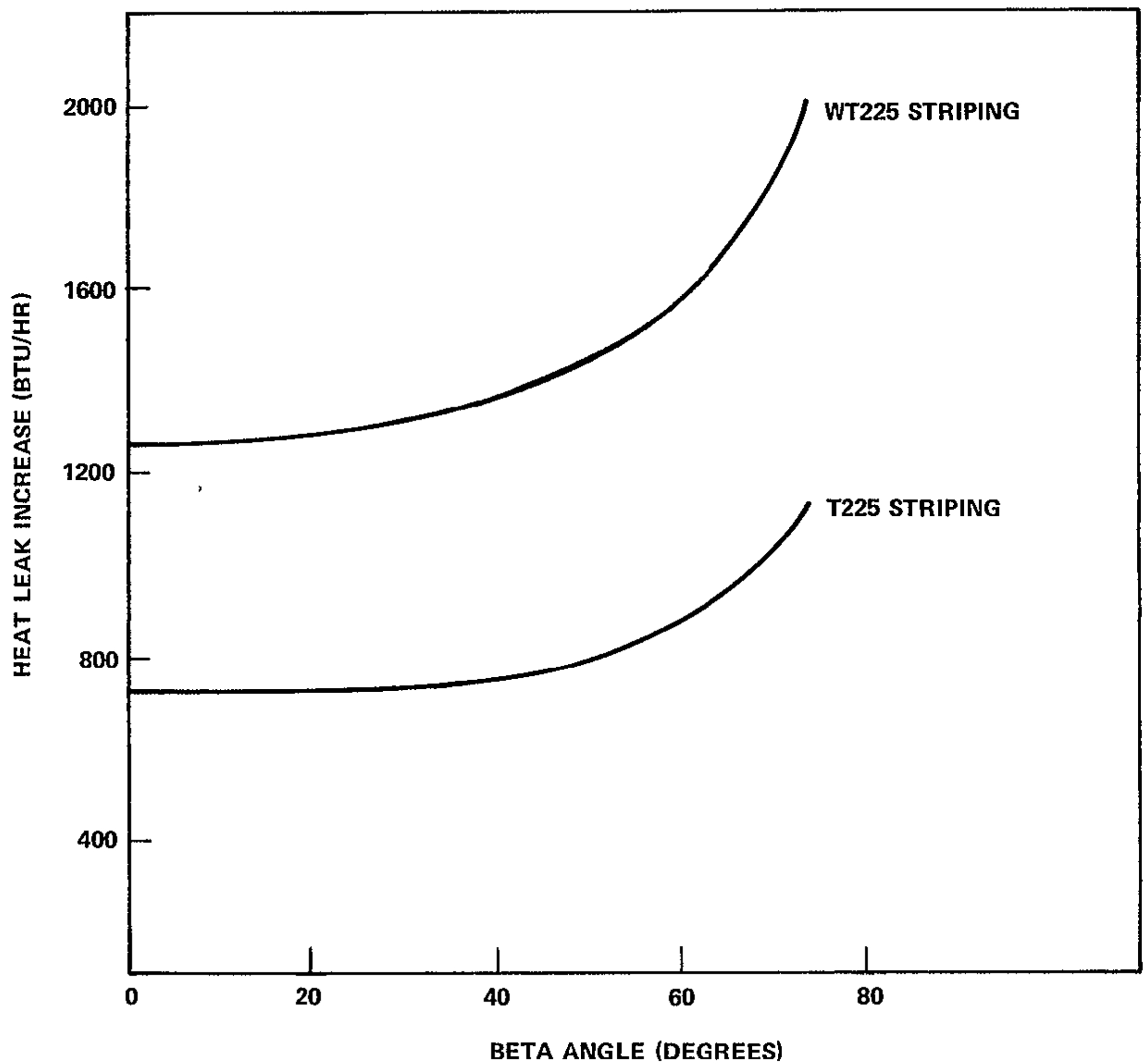

FIGURE 12 - OWS HEAT LEAK INCREASE RESULTING FROM EXTERNAL STRIPING PATTERNS AS A FUNCTION OF BETA ANGLE

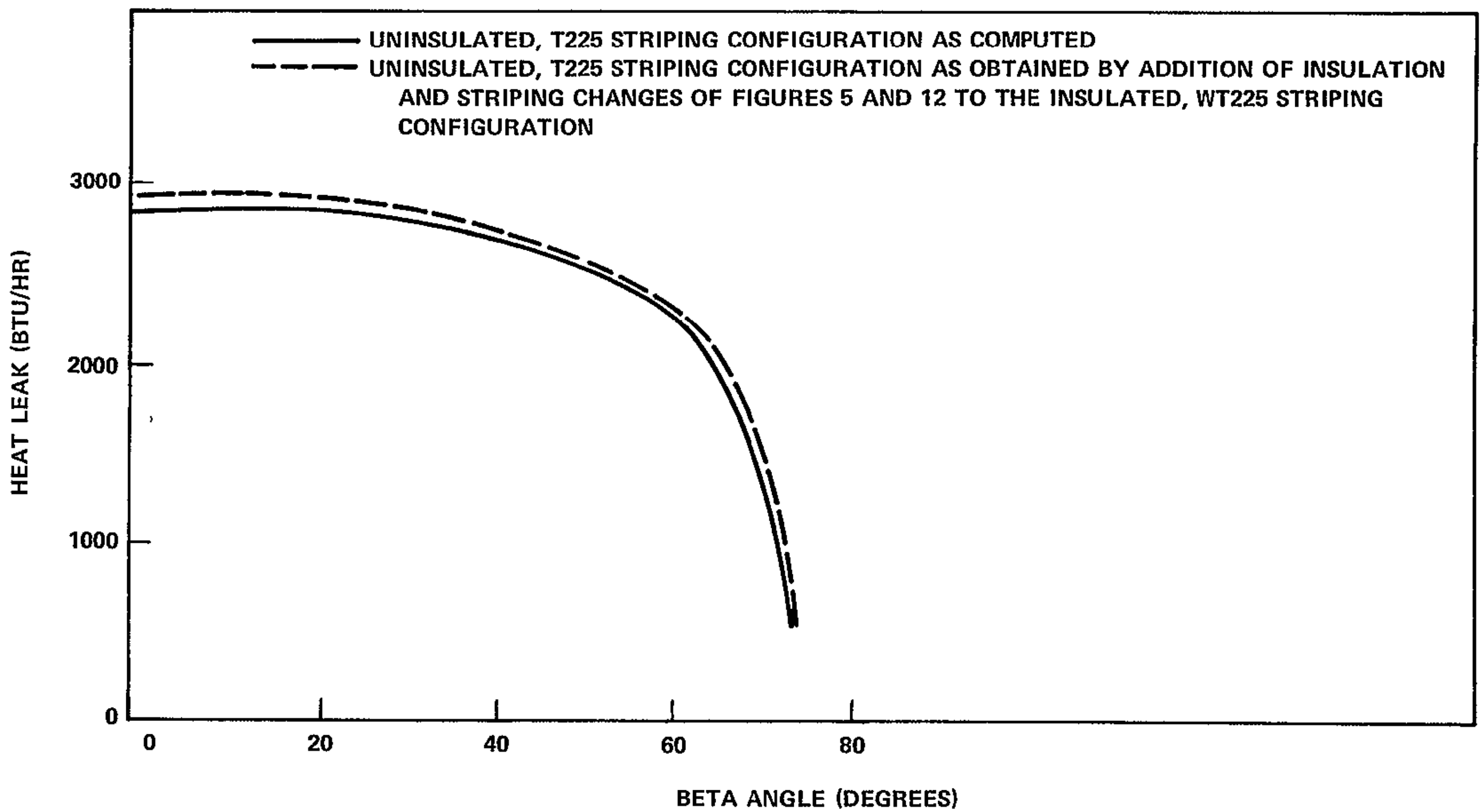

FIGURE 13 - OWS TOTAL HEAT LEAK AS A FUNCTION OF BETA ANGLE

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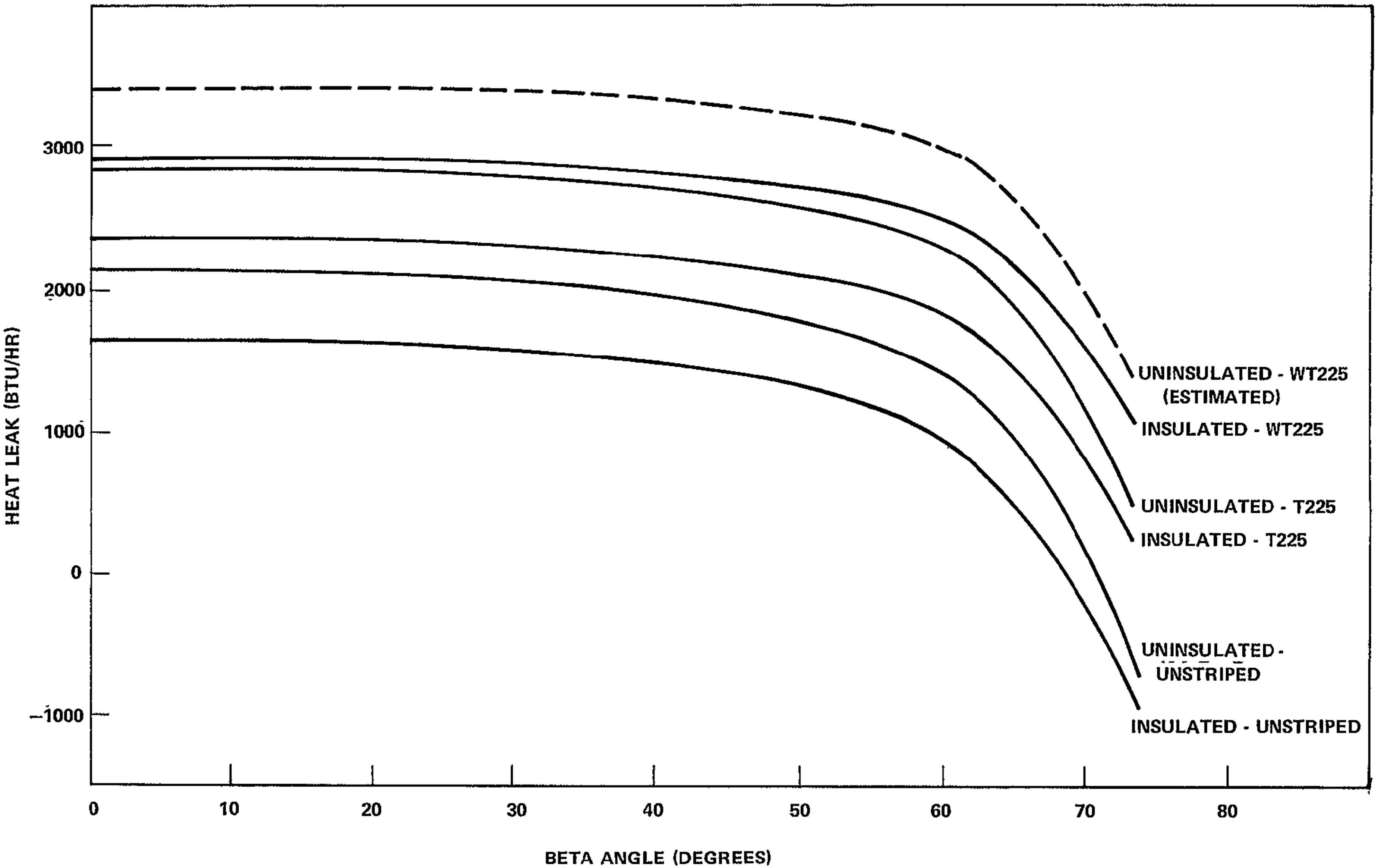

FIGURE 14 - OWS TOTAL HEAT LEAK AS A FUNCTION OF BETA ANGLE

BELLCOMM, INC

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